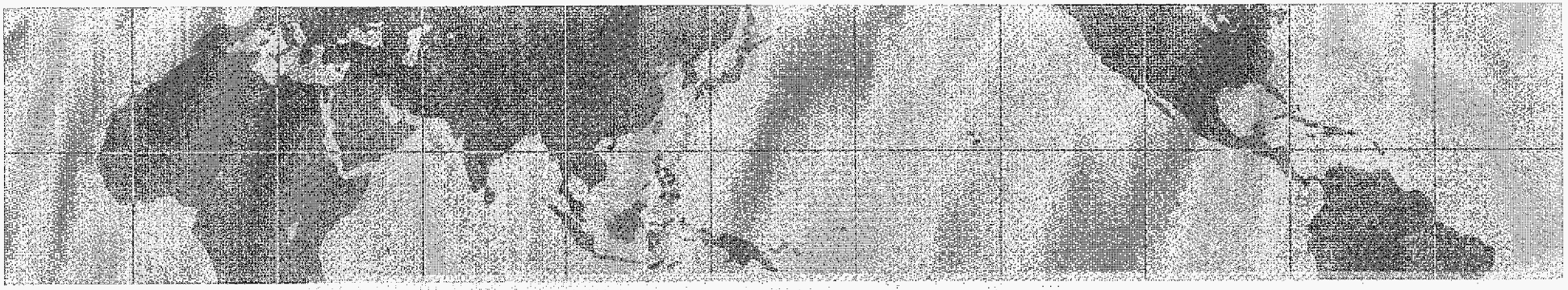


GPS - Revolution in Surveying and Geodesy

Ruth E. Neilan
International GPS Service Central Bureau
Jet Propulsion Laboratory, California Institute of Technology
http://igscb.jpl.nasa.gov/ ruth.neilan@jpl.nasa.gov

National Aeronautics and Space Administration

Start the Revolution

- Revolution takes *numerous* people
  - Offer one perspective on this
- NAVSTAR GPS
  - Navigation Satellite Timing and Ranging-Global Positioning System GPS
  - TRANSIT - first system 1963 - remarkable!
- GPS catalyst for change, amazing enabling information technology
  - Navigation, Surveying, Geodesy,…

INTRODVCTIO

GEOGRAPHICA PETRI APIANI IN DOCTISSIMAS VER-
neri Annotationes, cõtinens plenum intellectum & iudicium omnis operationis, quæ
per sinus & chordas in Géographia confici potest, adiuncto Radio astrono-
mico cum quadrante nouo Meteoroscopii loco longe vtilissimo.

HVIC ACCEDIT Translatio noua primi libri Géographiæ Cl. Ptolemæi.
Translationi adiuncta sunt argumenta & paraphrasis singulorum capitum libellus
quõq; de quinque terrarum orbis in plano figurationib' Authore Vernero.

LOCVS etiam pulcherrimus desumptus ex fine septimi libri eiusdem Gẽogra-
phiæ Claudii Ptolemæi de plana terrarum orbis descriptione iam olim & à veterib'
instituta Gëographis, vnà cum opusculo Amirucii Constantinopolitani
de iis, quæ Gëographiæ debent adesse.

ADIVNCTA est & epistola IOANNIS de Regiomonte ad Reuerendissi-
mum patrem & Dominum D. Bessarionem Cardinalem Nicenum, atq; patris-
archam Constantinopolitanum, de compositione & fabricatione Meteros-
coscopii armillaris, Cui rectis iam operi PETRI APIANI accessit
Torquetum nõnullorum pulcherrimũ finis & vsibus.

INGOLSTADII. Cum Gratia & Priuilegio Imperiali. AN. M.D.XXXIII.

Figure 1
Geographia by Peter Apian, dated 1533.

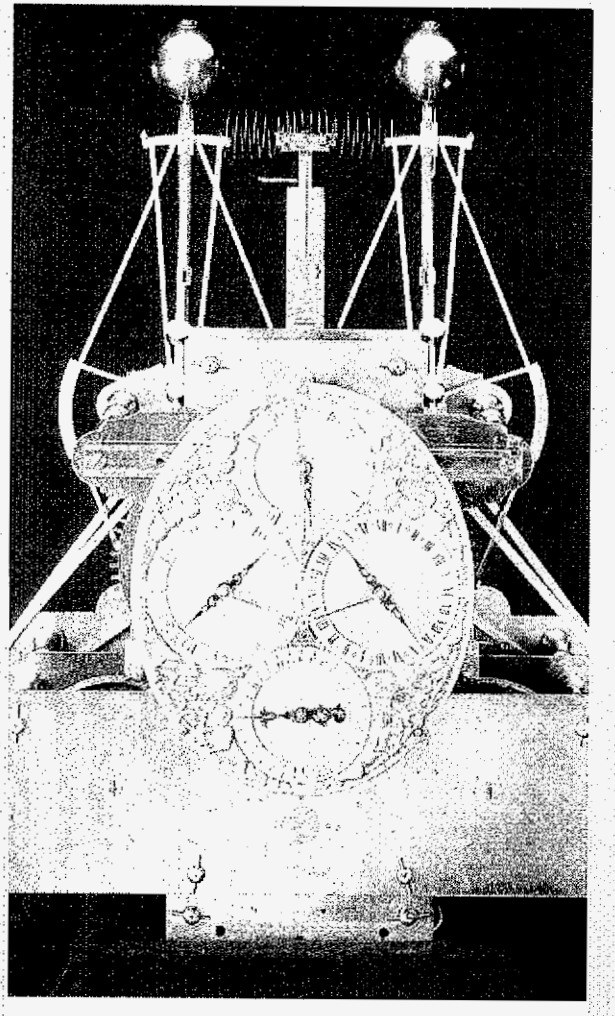
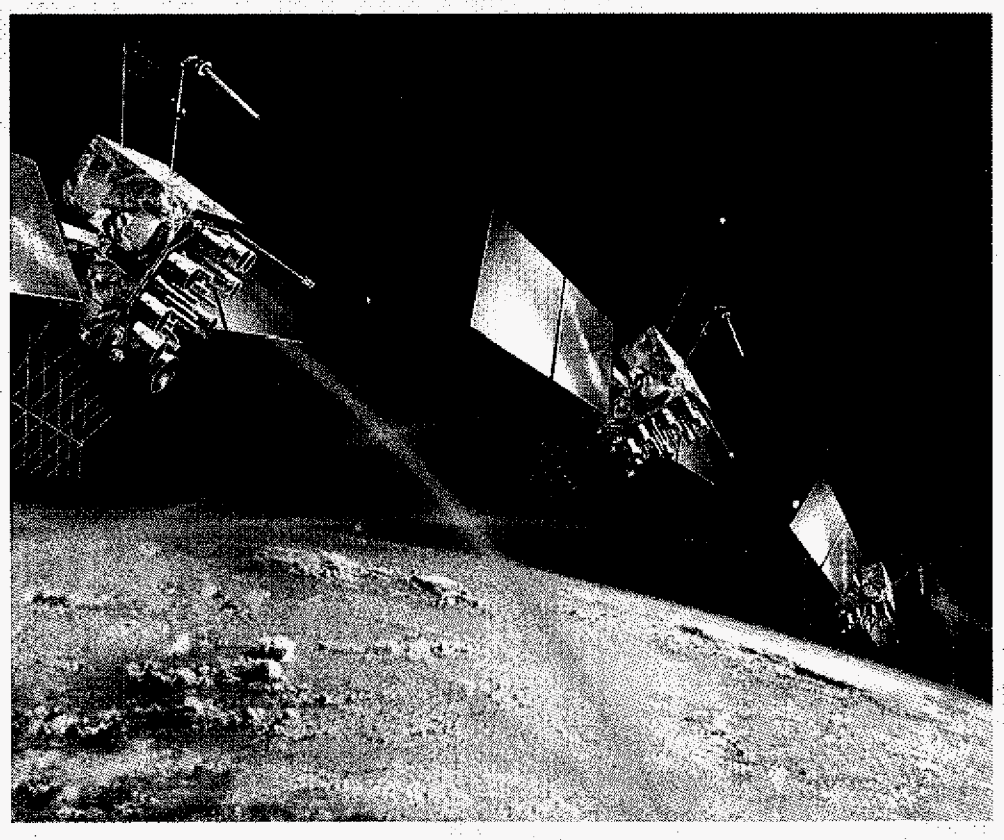


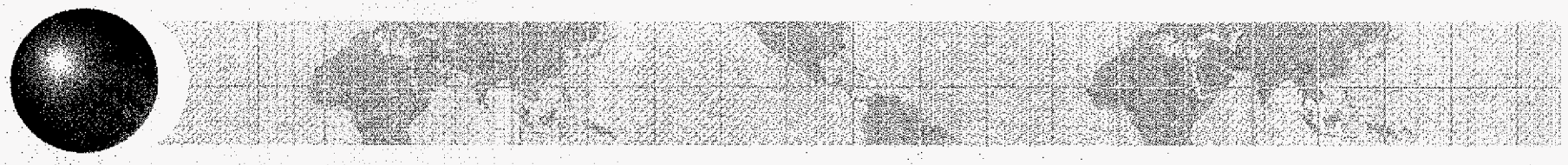
Figure 2
Harrison I, first marine Chronometer (credit: D. Sobel and W.J.H. Andrewes: Längengrad, Berlin Verlag 1999).

Global Positioning System



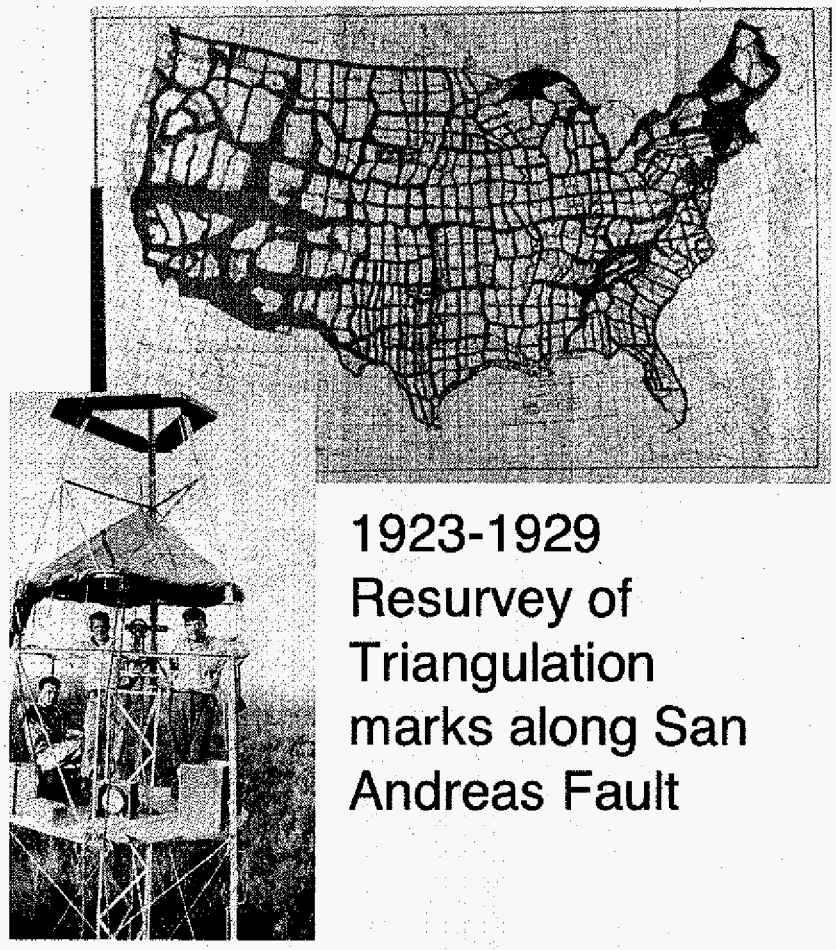
- Most significant recent advance in navigation and positioning technology. In the past, the ***stars*** were used for navigation. Today's world requires greater accuracy in real-time. The constellation of ***artificial stars*** provided by GPS do this.
- GPS uses satellites and ground equipment to determine position and time ***anywhere*** on Earth.

What a fantastic tool!

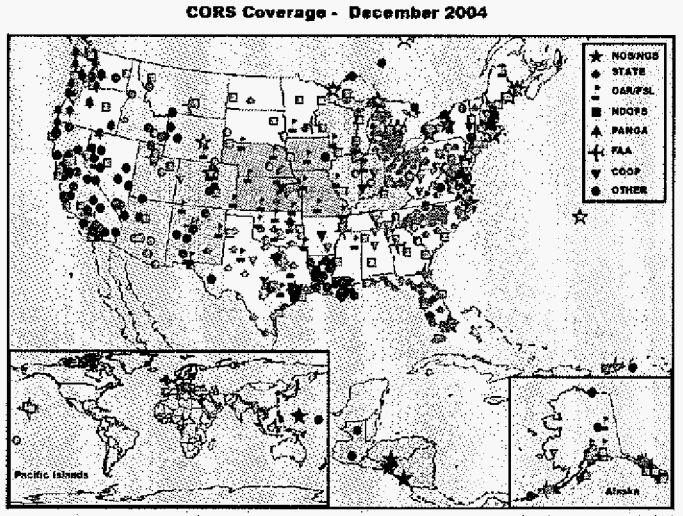


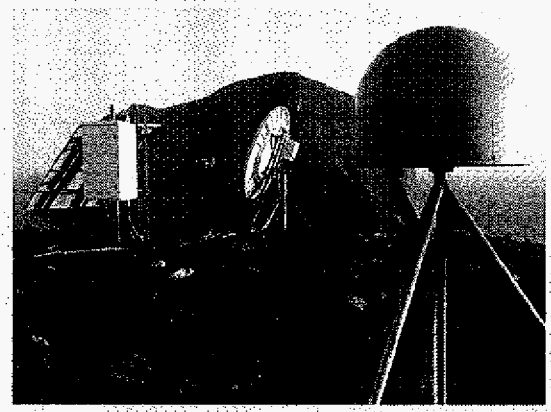
- Navigation
  - plan, record, and control the course and position of (a ship or aircraft)
  - navigation of a ship or aircraft based on the positions of celestial bodies
    - Astronavigation - *Augmentation systems today*
- Surveying
  - measurement of dimensional relationships: horizontal distances, elevations, directions, and angles, on the earth's surface especially for use in locating property boundaries, construction layout, and mapping
- Geodesy
  - science of measuring and monitoring the size and shape of the Earth

Same Objectives - New Tools

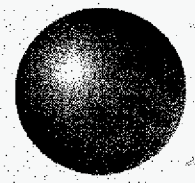


1923-1929
Resurvey of
Triangulation
marks along San
Andreas Fault





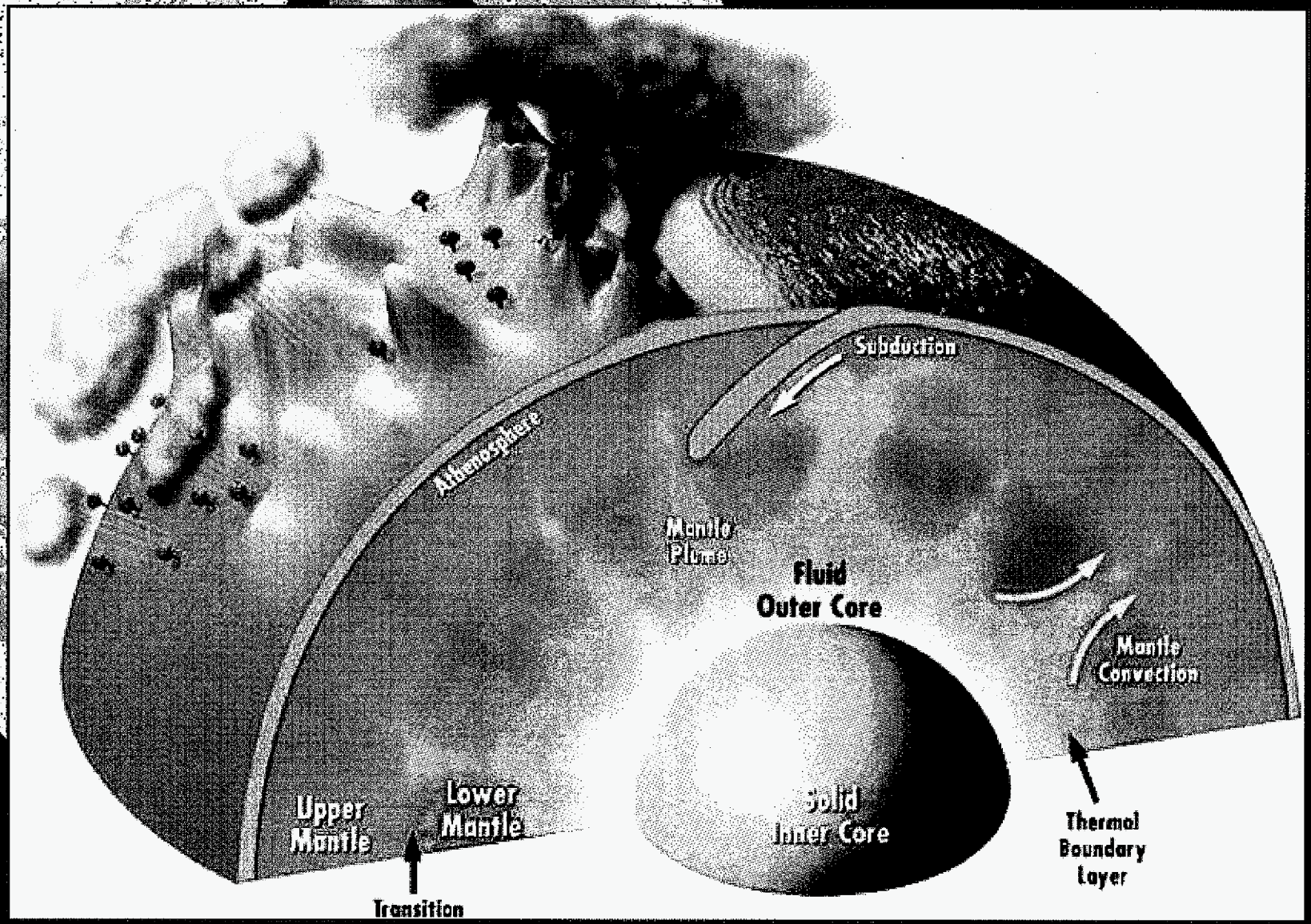
US CORS
network
today



Geodesy evolves

- Studying the motions of heavenly bodies and the shape and size of the Earth
- Now is the science of also studying their changes and the complex dynamic processes that interact within the planet
  - varying temporal scales of seconds to geological
  - length scales of millimeter to planetary radius and beyond

Geodesy: Measurement Of the Earth and its Potential Fields

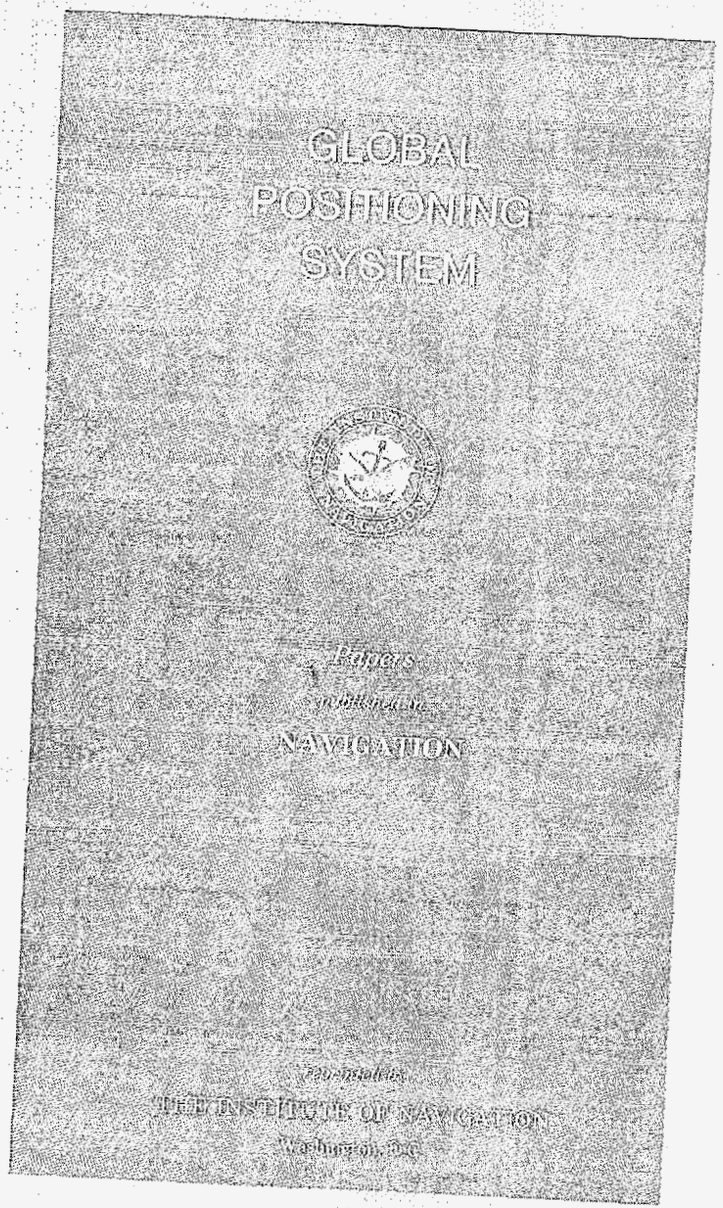


GPS Policy Affects Civil Use - 1980

One of the notable Federal coordination efforts associated with GPS occurred in 1980 when NOAA, NASA, and USGS joined with the Department of Defense (DoD) to complete the "Interagency Coordination Plan for Development of the Application of the NAVSTAR Global Positioning System (GPS) for Geodetic Surveying" (NOAA et al. 1980). The 1980 coordination plan identified specific roles for each agency in the development of GPS applications, in the testing of GPS concepts, and in the eventual selection of the optimum method, based on costs and performance, for general use. This cooperative effort culminated in the first interagency tests of GPS receivers which was conducted in January and February 1984 in Southern California. The results were reported at the fall meeting of the American Geophysical Union in San Francisco (Goad et al. 1984).

New Policy: Space Based Position Navigation and Timing, December 2004

The GPS 'Red Book'



GPS Signal Structure and Performance Characteristics

J. J. SPILKER, Jr.

ABSTRACT

DETAILS OF THE GPS signal structure are discussed as relates to the signal generation and the performance of the navigation system. GPS performance objectives, orbit geometry, and propagation effects are summarized in order to gain better understanding of the signal and what characteristics it must provide. With three performance objectives as a preface, the details of the signal are described, showing the details of the dual frequency transmission and both the precision P and clear/acquisition C/A codes and their characteristics. Finally, the basic performance of simplified receivers operating on this received signal is discussed. It is shown that an rms position error of less than 10 meters is well within the achievable performance bounds of the system.

SECTION 1—INTRODUCTION AND PERFORMANCE OBJECTIVES

1.1 Introduction

In this paper we describe the detailed signal structure used in the Global Positioning System satellite navigation system. In order for one to understand the performance characteristics in a meaningful sense, we begin by discussing, in an idealized sense, the concepts for high accuracy, real-time navigation using satellites. The various perturbation effects on the navigation signal and overall system are then described. These perturbations include relativistic effects, multiple access interference between satellites, tropospheric and ionospheric propagation delays, multipath, thermal noise, and other interference effects. We conclude the first section with a summary of the performance objectives for the signal.

The paper then continues with a detailed discussion of the signal structure, the code properties, and the performance of the signal relative to the various objectives and constraints in the first section.

In the concluding section the performance capability of a typical receiver for this signal is described and briefly analyzed. The search, acquisition, and tracking accuracy for the GPS codes are included. Effects of user dynamics are considered. Multipath and other interference error effects are summarized.

1.2 Performance Objectives

There are several key performance objectives for the GPS system which distinguish it from previous satellite and landbased navigation systems. Some of the more important are summarized below:

- High Accuracy 10–20 meter rms position error
- Real-Time navigation from users with high dynamics
- World-Wide Operation
- Tolerant to Nonintentional or Intentional Interference

In addition to these constraints, the user cannot be required to carry a precision atomic clock, and an initial navigation fix should be obtained within a reasonable period (minutes rather than hours) after initial turn-on of the receiver.

Obtaining high accuracy in real-time without ambiguity requires a relatively large bandwidth (20 MHz) and a signal with a long period. The

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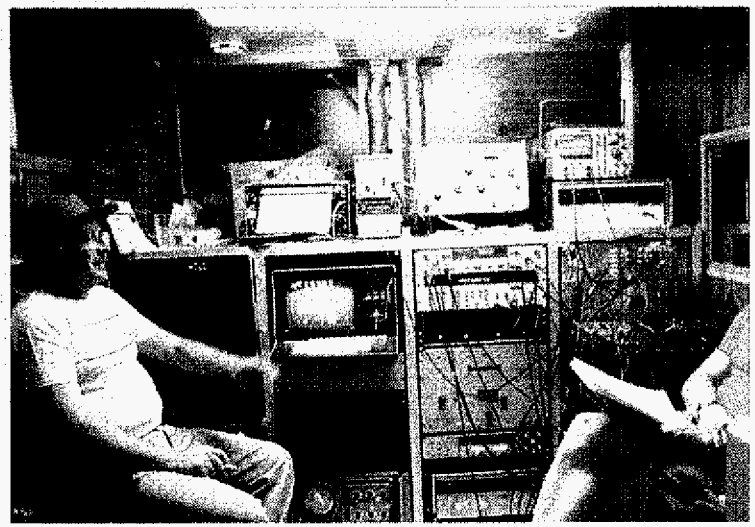
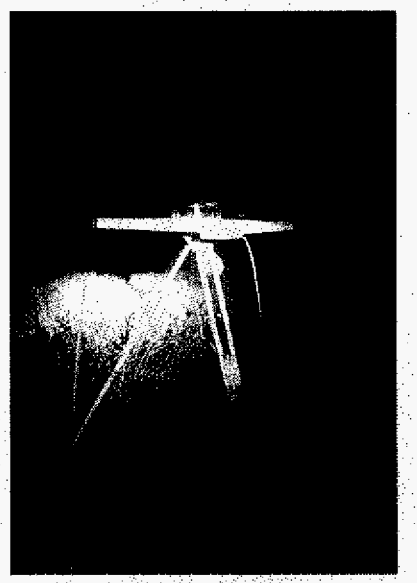
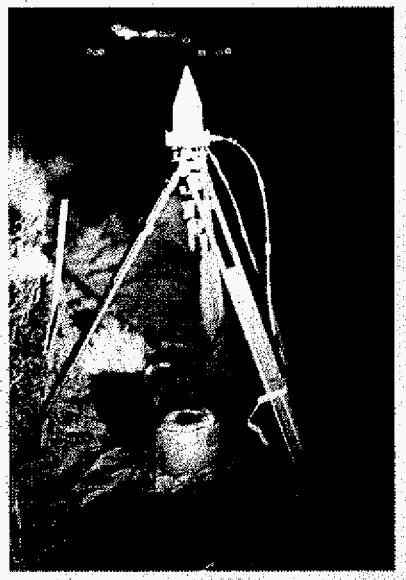
SERIES - Satellite Emission Range Inferred Earth Survey System

Figure 1. One of the two SERIES proof-of-concept stations. Data aquisition electronics occupy a small portion of the camper shell. The antenna is a 1.5 meter diameter, prime focus feed dish mounted on a two axis (azimuth and elevation) drive.

Inside the SERIES Truck

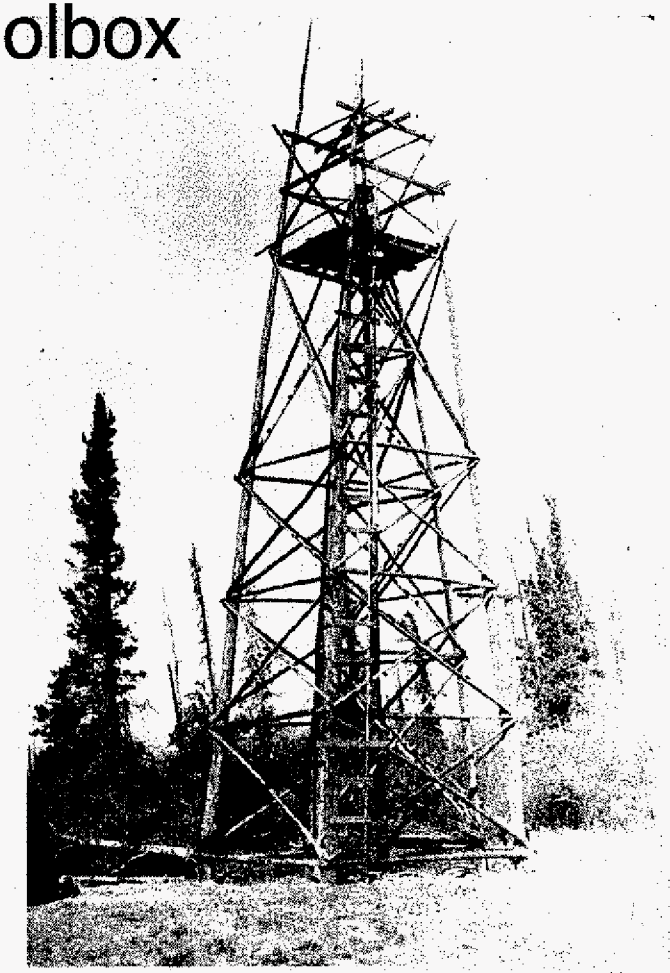


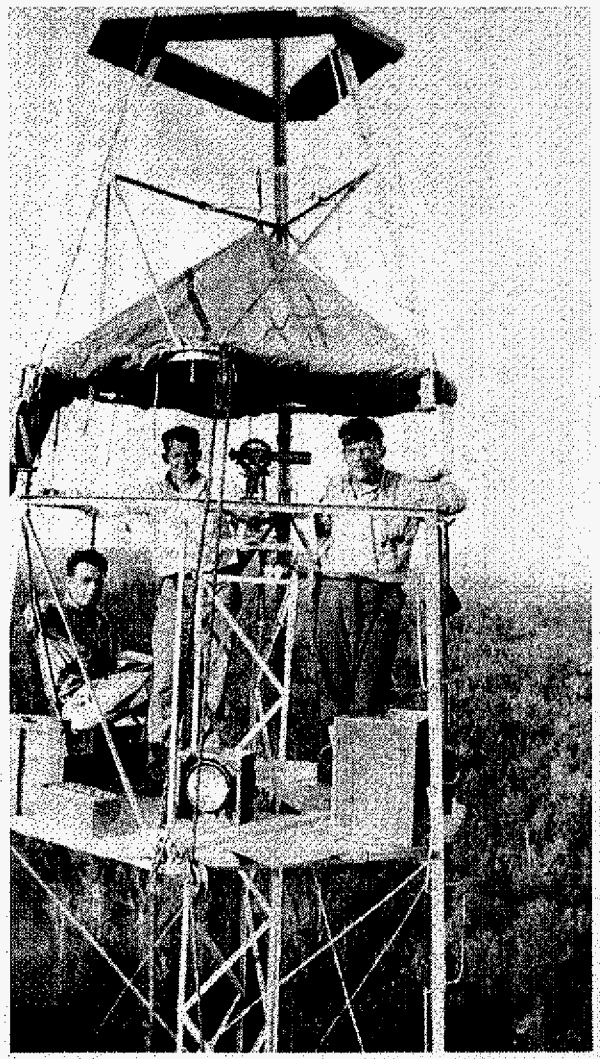




Macrometer & TI-4100

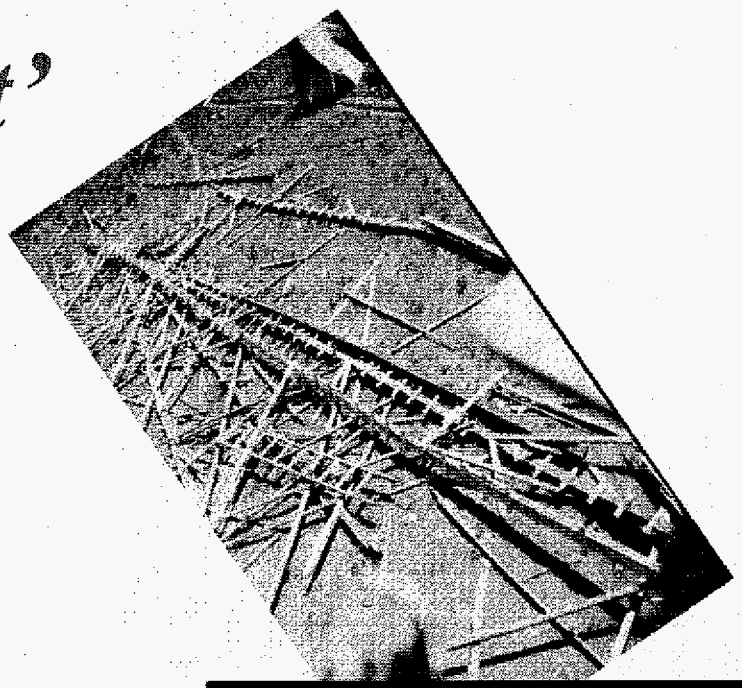
- Poignant example of the changing toolbox
  - Bilby towers

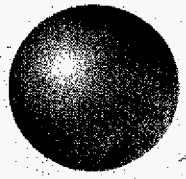




1st US Interagency GPS Receiver Tests
The 1984 'Shootout'

- January-February 1984
  - NOAA, NASA,USGS, DoD
  - Coordination based on 1980 agreement
  - SERIES, SERIES-X, TI-4100, Macrometer
- Bilby towers collapse
  - *Basking in the Bilby fireglow, Southern CA*





1st International Symposium on Precise Positioning with the Global Positioning System POSITIONING WITH GPS - 1985

US Department of Commerce

Rockville, Maryland

April 1985

6 degrees of separation? How about 2 or 3? Or none?

Bossler's Paper

BACKGROUND OF FEDERAL GPS ACTIVITIES

The NAVSTAR GPS program is a joint service program managed by the U. S. Air Force with representation from the Army, Navy, Marine Corps, Defense Mapping Agency (DMA), Department of Transportation, NATO, and Australia. The National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), and the U. S. Geological Survey (USGS) also recognized early on that they each had an interest in either the development or in the application of GPS for geophysical and geodetic purposes.

One of the notable Federal coordination efforts associated with GPS occurred in 1980 when NOAA, NASA, and USGS joined with the Department of Defense (DoD) to complete the "Interagency Coordination Plan for Development of the Application of the NAVSTAR Global Positioning System (GPS) for Geodetic Surveying" (NOAA et al. 1980). The 1980 coordination plan identified specific roles for each agency in the development of GPS applications, in the testing of GPS concepts, and in the eventual selection of the optimum method, based on costs and performance, for general use. This cooperative effort culminated in the first interagency tests of GPS receivers which was conducted in January and February 1984 in Southern California. The results were reported at the fall meeting of the American Geophysical Union in San Francisco (Goad et al. 1984).

NASA Activities

Under the GPS coordination plan, the NASA role and mission were to:

1. Develop and demonstrate interferometric GPS positioning.
2. Participate in the development of advanced GPS receivers.
3. Use GPS for accurate positioning of satellites.

A major aspect of NASA's involvement has been the development of the Satellite Emission Radio Interferometric Earth Surveying (SERIES) concept (MacDoran et al. 1982). More recently, NASA has been actively involved with applications of GPS for crustal motion monitoring and with the development of GPS orbit prediction and tracking systems. NASA/Jet Propulsion Laboratory is conducting another interagency test this spring. That activity is the subject of one of the presentations at this conference. NASA is also investigating the use of GPS receivers on board geodetic satellites for precise ephemeris determination throughout scientific missions.

NOAA Activities

The NOAA activities related to GPS fall under the basic National Geodetic Survey authorization and include:

1. Using GPS for operational geodetic control surveys.
2. Development of specifications for GPS operations.
3. Investigations and research in GPS-related technology.
4. Using GPS results for monitoring and modeling crustal motion.

In addition to the active participation of National Geodetic Survey, NOAA contributed to a tri-agency receiver development project through a contract with the Applied Research Laboratories, The University of Texas at Austin. DoD and USGS also participated in this contract which lead to the current hardware

available from Texas Instruments. NOAA is currently using the Texas Instruments TI 4100 as well as the MACROMETER(DI) V-1000 for operational GPS surveys. Several of NOAA's ideas and programs will be presented at this meeting. Preliminary results from simultaneous mobile very long baseline interferometry (VLBI) and GPS surveys in Alaska will also be presented.

DoD Activities

Within DoD, DMA serves as Deputy Program Manag
Additionally, DMA provides:

1. Static positioning tests for the GPS/Joint
2. Development of GPS satellite for LANDSAT
3. Point of contact for the geodesy interest
4. Lead in tri-agency development of GPS rece

Under a separate agreement, the DoD GPS role als
Geophysical Laboratory (AFGL) research and devel
in response to DMA requirements in mapping, char
activities have included extensive GPS research
receivers for precise relative geodesy and orbit
Draper Laboratory (CSDL) and at the Massachusett

USGS Activities

The USGS is primarily concerned with its geophy
GPS from the perspective of a user. USGS GPS act

1. Identify applications of GPS to USGS progr
2. Provide support for GPS research at CSDL a
3. Contribute towards the tri-agency prototyp

Currently, the USGS is purchasing five GPS receiv
networks now being measured by other techniques,
regions of California (Kerr 1985).

FGCC Activities

The Federal Geodetic Control Committee (FGCC) h
Federal agencies involved with geodetic surveying
include the testing and evaluation of new surveyi
establishment of standards and specifications for

In January 1983, the FGCC Instrument Subcommitt
demonstration of the MACROMETER(DI) interferometric
Fronczek 1983). The tests compared MACROMETER(DI)
azimuths, and ellipsoidal height differences with
The test showed that the MACROMETER(DI) V-1000 is a
be used successfully to establish geodetic contro
National Geodetic Reference System.

ICCG GPS Panel

Under the auspices of the Interagency Coordinat
(ICCG), Federal agencies involved with GPS will c

purpose of the recently reconstituted ICCG GPS Panel for Operational Coordination
and Long Range Planning will be to:

1. Compile agency needs and plans for use of GPS receivers.
2. Formulate procedures for interagency sharing of receivers.
3. Facilitate cooperative data acq
4. Develop standardized data forma
5. Recommend procedures and locati

this panel has just been formed and i
meeting tentatively scheduled for Oct

GPS SATELLI

The recent launch of the tenth GPS
the testing and development phase.
operational GPS satellites has planne
continuing on until December 1988.
satellites are available and configu
expected to begin in late 1987. The
available by the end of 1988.

FEDERAL

As referred to earlier in the instr
dependent on access to the C/A (coars
code for field operations. These cod
transmissions and provide timing, sat
position information. Other systems
"codeless" mode, treating the GPS sat
interferometric measurement technique

Separate from the field use code re
processing of GPS data with precisely
the highest quality geodetic results.
past orbit ephemerides must now be ex

C

The C/A code, under the DoD label c
will be made available to a wide vari
broadest possible commercial, civil,
world. However, the GPS system will
SPS accuracy during times of national

Access to the P code, under the DoD
is another matter. Originally the D
applications of high national securit
to the U. S. and Allied military user
policy on GPS use in the civil commu

Under the proposed policy framewor
could apply for access to the PPS.

application to ensure consideration of national security needs. Once an application has been approved, a certification would be issued specifying the geographic area and time frame. The approved applicant would then contract with the U. S. Government, or perhaps a third party agent, for delivery of the equipment, the cryptography, and the supporting services. Additional details on this access policy will be covered later in this session.

Precise Ephemerides

Under a proposed agreement, NOAA, NASA, and DMA will participate in the tracking of the 18 GPS satellites, computing the precise ephemerides for the satellites, and then distributing the ephemerides to military and civilian users for post processing of their GPS observations (NOAA et al. 1984). The computations and distribution activities will be for the purpose of providing geodetic quality data, and will not occur in real time.

In addition to each agency providing technical expertise to support the development of orbit determination procedures, the specific NOAA responsibilities will include:

1. Operating satellite tracking stations at MIRI sites in Massachusetts, Texas and Florida.
2. Distributing the tracking data and geodetic quality ephemerides generated at DMA to domestic requestors.

The specific NASA responsibilities will include:

1. Operating tracking stations in Spain, California, and Australia.
2. Providing tracking data and geodetic quality ephemerides to those with whom NASA has cooperative research programs.

The specific DMA responsibilities will include:

1. Establishing agreements for the operation of some tracking stations.
2. Operating the Satellite Tracking Network Control Center.
3. Maintaining the Satellite Tracking Data Base.
4. Generating the geodetic quality ephemerides.
5. Providing the precise ephemerides to foreign requestors.

The proposed agreement has been accepted by both NOAA and NASA. We are now awaiting final approval from DMA where the memorandum of understanding is being circulated for comments.

SUMMARY

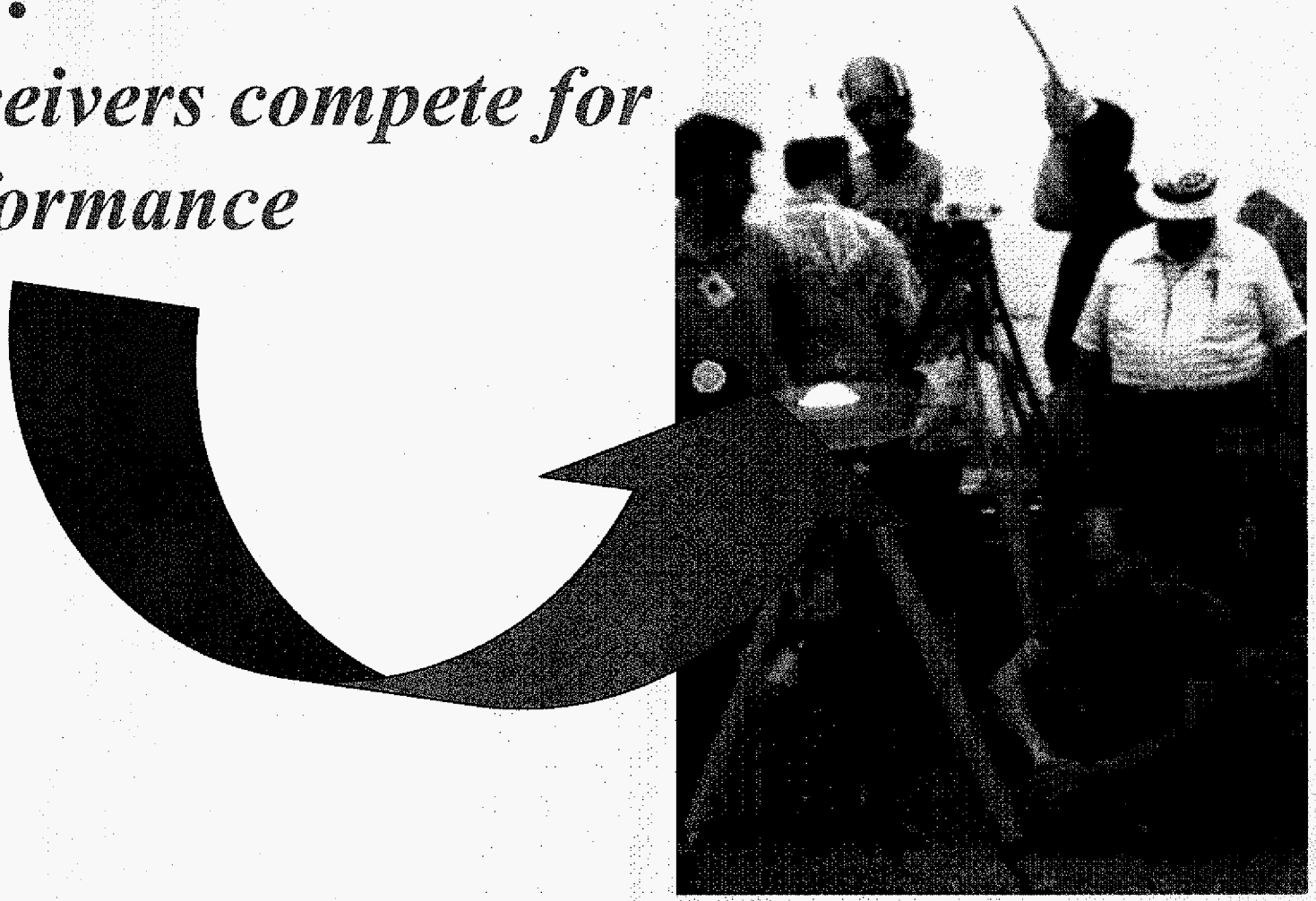
The GPS will permit rapid, economic point positioning with accuracies of a few centimeters over distances of 100 km or more. The development of GPS geodetic surveying instruments has come about because of the significant cooperation within the Federal sector. This cooperation, together with the recognition of GPS potential by the private sector, brings us to this symposium today. Those of us in the Federal environment recognize our roles and our responsibilities to provide orbits, standards and specifications, SPS access, limited PPS access, continued research and development, and to continue and expand our cooperative relationship with the civil sector.

Observation Changes

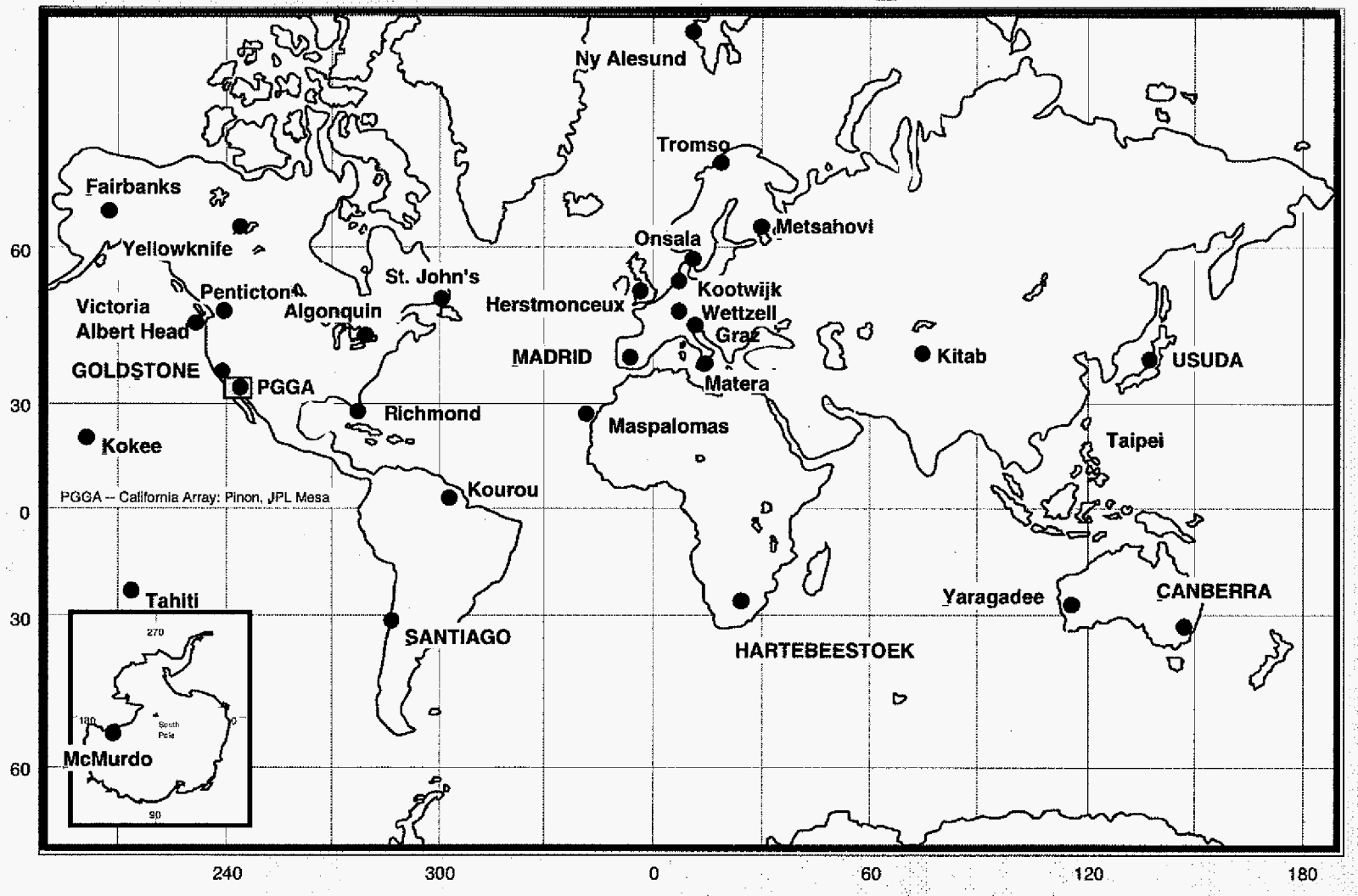
NASA Geodynamics, Baja Mexico '89

Rivalry?

GPS Receivers compete for best performance

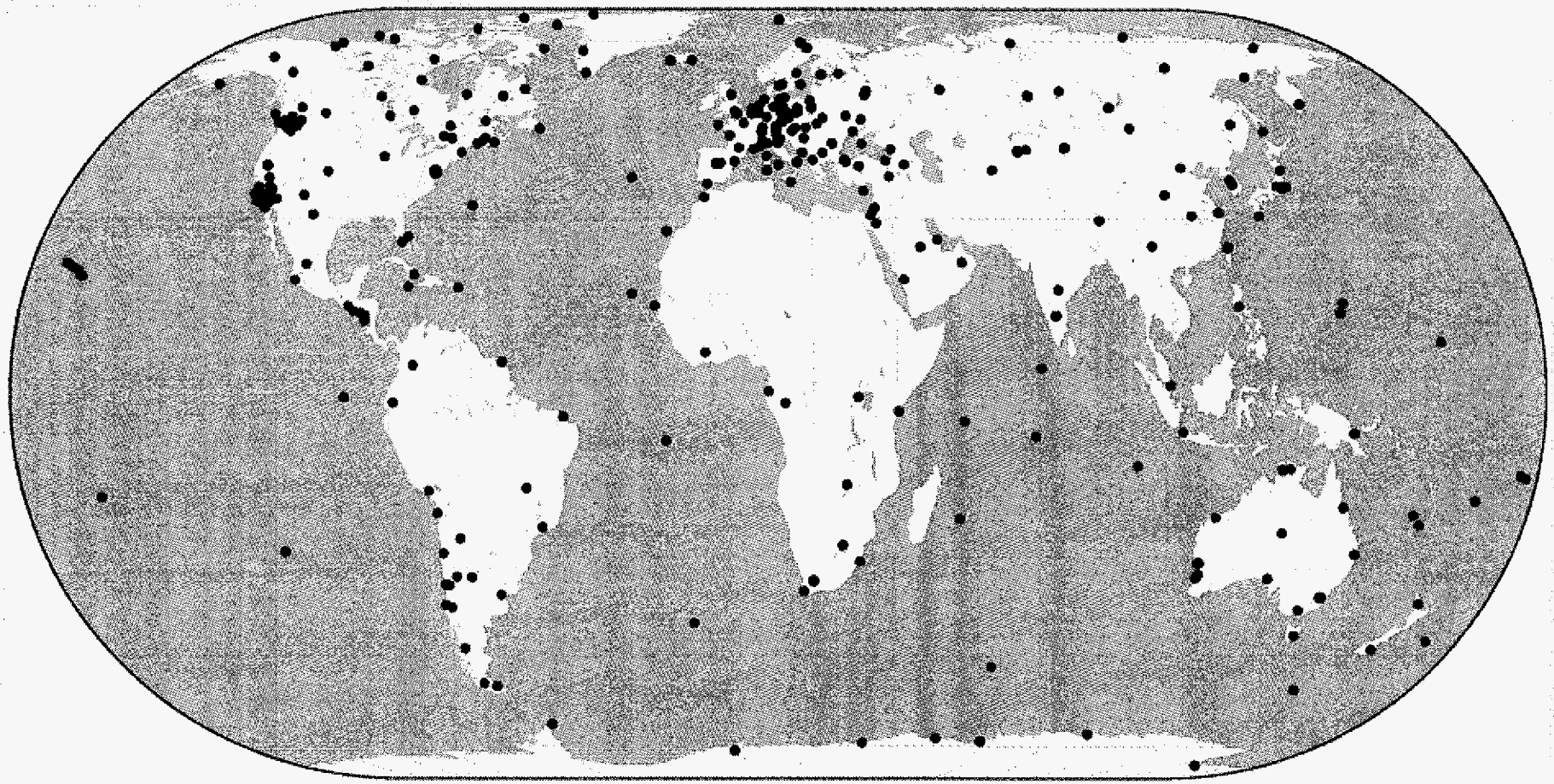


Global GPS Network Map 1991-1992



IGS GNSS Tracking Network

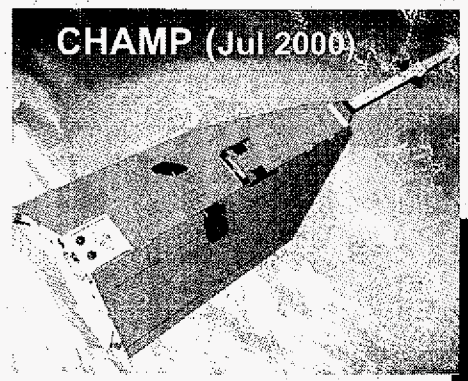
(GPS + GLONASS)

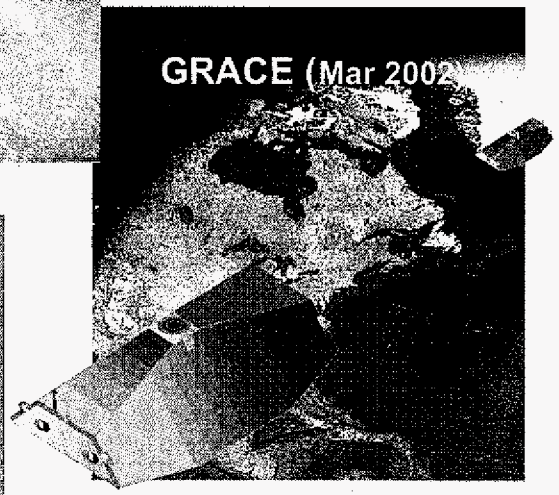


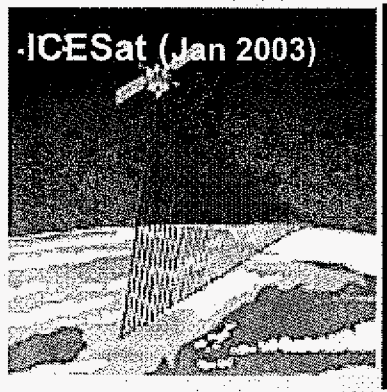
GMT Oct 13 17:33:43 2004

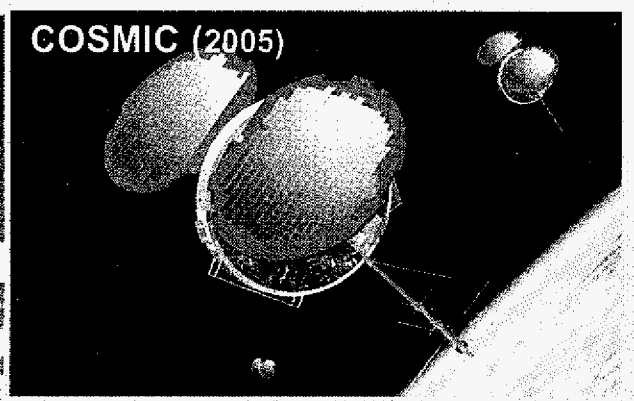
http://igscb.jpl.nasa.gov/network/netindex.html

GPS Precise Navigation - Low Earth Orbiters

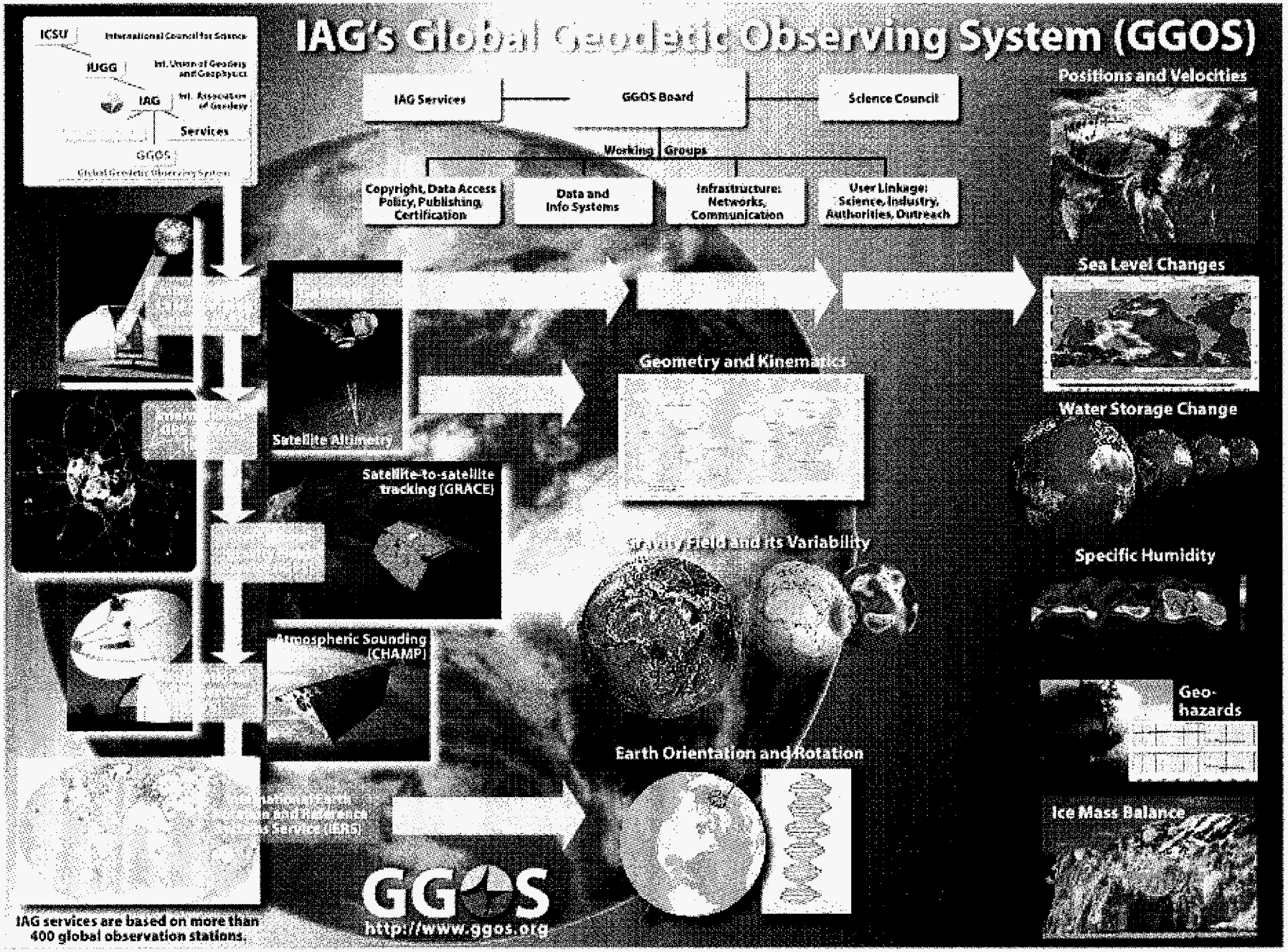






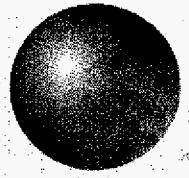


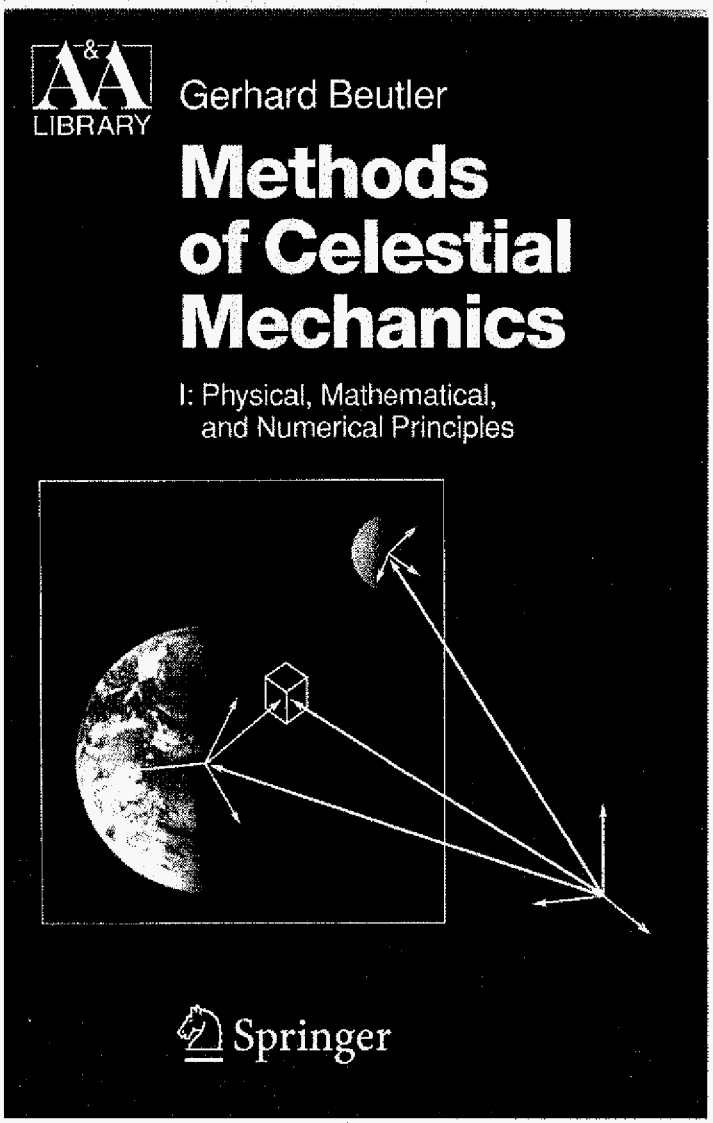
- *GPS Flight Receiver on board each*
  - *IGS LEO Project focuses on precise orbit determination*
- *LEO Missions Objectives/ Science Goals include:*
  - *Atmospheric remote sensing*
  - *Gravity, Magnetics*
  - *Ionospheric remote sensing*
  - *Ice and oceans*


IAG's Global Geodetic Observing System (GGOS)
ICSU
International Council for Science
IUGG
Int. Union of Geodesy and Geophysics
IAG
Int. Association of Geodesy
Services
GGOS
Global Geodetic Observing System
IAG Services
GGOS Board
Science Council
Working Groups
Copyright, Data Access Policy, Publishing, Certification
Data and Info Systems
Infrastructure: Networks, Communication
User Linkage: Science, Industry, Authorities, Outreach
Positions and Velocities
Sea Level Changes
Satellite Altimetry
Geometry and Kinematics
Satellite-to-satellite tracking (GRACE)
Water Storage Change
Specific Humidity
Atmospheric Sounding (CHAMP)
Earth Orientation and Rotation
Geo-hazards
Ice Mass Balance
IAG services are based on more than 400 global observation stations.
GGOS
http://www.ggos.org

Closing Remarks

- GPS sparked a fantastic revolution
  - Today applications are diverse as evidenced by the popularity of the Annual ION GNSS meetings
- Evolutionary phase continues
  - GLONASS, Galileo, Beidou
  - WAAS, EGNOS, QZSS, GAGAN
- Challenges - seamless utilization with multiple signals, time systems, receiver choices
  - Reference frame of fundamental importance

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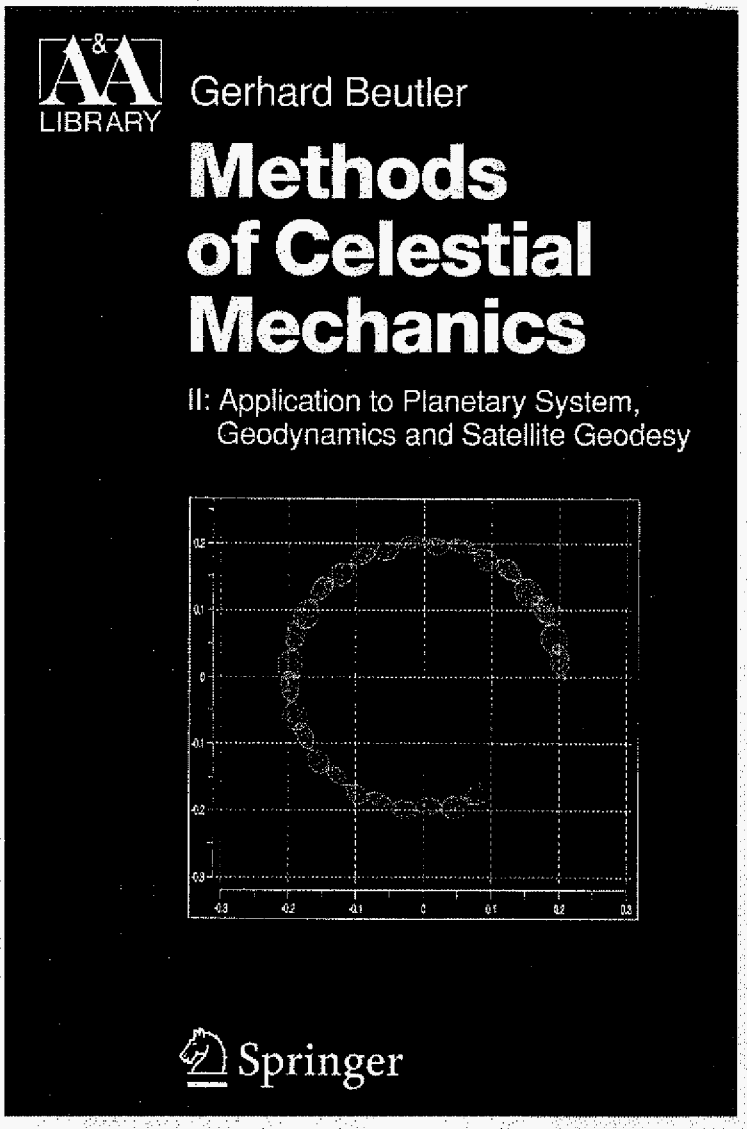
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Acknowledgments

- NOAA's National Ocean Service Education: Geodesy
  - http://oceanservice.noaa.gov/education/kits/geodesy/supp_geo_roadmap.html
- NOAA Photo Library - Historic Album
  - http://www.photolib.noaa.gov/historic/c&gs/geodesy.html
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- Overview GPS Surveying
  - http://www.gmat.unsw.edu.au/snap/gps/gps_survey/contents/overview.htm
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